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Review Article

Forensic Geomorphology

Alastair Ruffell and Jennifer McKinley[a]

[a]*School of Geography, Archaeology & Palaeoecology, Queen's University, Belfast, N.Ireland. BT7 1NN*

Telephone: 00442890973350 Fax: 0044289097321280 Email: a.ruffell@qub.ac.uk

ABSTRACT

Geomorphology plays a critical role in two areas of geoforensics: searching the land for surface or buried objects and sampling or imaging rural scenes of crime and control locations as evidence. Most of the associated geoscience disciplines have substantial bodies of work dedicated to their relevance in forensic investigations, yet geomorphology (specifically landforms, their mapping and evolution, soils and relationship to geology and biogeography) have had no such exposure. This is strange considering how fundamental to legal enquiries the location of a crime and its evolution are, as this article will demonstrate. This work aims to redress the balance by showing how geomorphology is featured in one of the earliest works on forensic science methods, and has continued to play a role in the sociology, archaeology, criminalistics and geoforensics of crime. The application geomorphology has in military/humanitarian geography and environmental/engineering forensics is briefly discussed as these are also regularly reviewed in courts of law.

Keywords Forensic Science; Geoforensics; soils; landforms; crime; burials

1. Introduction

Forensic in the context of this article is taken to be pertaining to the law, and thus commonly includes the criminal investigations that are central to this review (homicide [murder in some countries], kidnap, theft, rape, smuggling, extortion), but also scientific investigations that may be anticipated as coming before a court of law. The word has been placed in front of almost every area of study one can imagine, from the well-established forensic chemistry/biology/psychology, to the more recent use of forensic accountancy/cookery/something missing?. What is most surprising is that most, if not all, of the geoscience sub-disciplines have found application in criminal or legal investigations, from forensic archaeology, pedology, geology, geophysics, geoscience to geoforensics. The diversity of terms is baffling: Ruffell (2009) attempted to define the origin and scope of the above. To add to the milieu, but also to redress the balance, the application of geomorphology to investigations into serious criminal activity (see above for scope) is here considered. This is somewhat surprising, given that one of the earliest handbooks on forensic science (or criminalistics), included sections on geography and geomorphology (Gross, 1893, see below). Indeed Schumm (2005) implores his geomorphologist colleagues to not be afraid of being involved in cases of litigation, they being the best qualified scientists available to comment on changing water courses, the causes of landslides or environmental pollution and the reasons for buildings failure on unstable ground. We hope this article reinforces and perhaps expands on that of Schumm (2005). In this article, 'forensic' aspects of physical geography, geomorphology and landform mapping are considered. We briefly include environmental, military, humanitarian and engineering enquiries, these being too vast in their scope for one review. Also not considered here in detail is the association between the psychology of the perpetrator and/or victim and landscape morphology. This area of what is essentially criminal profiling is a huge subject beyond the scope of this work, although elements are mentioned where relevant of course, as all acts subject to forensic analysis were conducted by people in a place. This reflects a fundamental principle in this work: that the shape of the land influences or controls human activity, and that this can be applied to geoforensics, in the above sense. The articles chosen for review reflect personal preference for each of the subject sub-headings and are not exhaustive. Many of the works, especially edited volumes, contain sufficient literature to allow the reader to explore the literature in each of the sections (below) discussed.

Commented [JM1]: really?

Soil, sediment and rocks have all been used in criminal investigations since 1854 (Scientific American, 1854). However, the first use of any of the geoscience disciplines with the word forensic was by Brooks and Newton (1969), who used the term ' forensic pedology'. This was followed by Murray and Tedrow (1975), with their book 'Forensic Geology'. Although the shape of the land or Earth's surface and the way it has evolved is critical to many investigations such as searching, sampling and how people behave in a landscape, the term forensic geomorphology has never been used in a stand-alone publication, which is peculiar given the importance of the landscape in investigations (knowingly or not on the part of the investigator), as the review (below) will hopefully demonstrate. The closest publication to this work in terms of scope is Ruffell and McKinley 's (2008) chapter of the same title, where some aspects of geomorphology in criminal investigations were discussed. The current work differs in concentrating on a review of published work that uses the morphology of the land, changing soil/landuse types and or associated biogeography in forensics. The article is arranged roughly chronologically (the section on the FBI perspective by Boyd [1979], is placed later, to fit with the sociological perspective) and where appropriate by author name, as many individual workers have developed their work in successive articles. This layout hopefully reflects the development of the uses of geomorphology, as well as demonstrates how advanced some early works were.

2. The Historic Perspective: Hans Gross's 1894 'Handbook for Examining Magistrates'.

This book is important in forensic science in that it is one of the first comprehensive texts on conducting crime scene examinations. Gross's book is all the more remarkable in that it includes many sections on physical geography/geomorphology, as well as urban and peri-urban geography: all far in advance of many later works. Gross saw the whole landscape as a dynamic and interacting environment, indicating that an investigator should familiarise themselves with both the concept of scale as well as geography: 'hotels, public houses, clubs and brothels, because of the brawls that may take place in them. Ponds and wells in villages on account of possible accidents by drowning, forests because of poaching and illicit felling.' The most relevant (to this review) section of Gross's book is as visionary as the rest of his book is to forensic science in general. The section is entitled 'Sketch of a Larger Portion of Country' (p. 247) and it disguises what is actually contained, which ~~is~~ constitutes the first landscape-based crime scene map ever published (see below). Gross starts with a comment that making a drawing of large-scale features is a challenge, all the more so as he was working in a time before the kinds of topographic maps (e.g. 1:25,000, 1:50,000 scale produced by most of the Ordnance Survey departments of the world) geomorphologists are used to working with had been completed. Gross was also working prior to the invention of accurate measuring devices. As well as large-scale mapping being 'difficult' he makes an initial statement 'at times it is important to know whether the spot may be seen from a distant point', an obvious reference to the shape of the land, to covert activity, to viewability from afar, and years ahead of Geographic Information Systems (or Science: both GIS) applications such as viewshed analysis. In his Figure 34 (p. 248) Gross attempts to integrate physical and human features of the environment that were pertinent to his view as a crime scene investigator. Such is the historical importance of this figure, plus the fact that many readers of Geomorphology may be gratified to see such maps in a book on criminalistics, prompted us to re-draft his map (Figure 1). Gross returns to considering the shape of the land in his section on topographic modelling, and considers contour maps, then actually making a model of the land from clay, partly to understand the environment of the scene of crime, but also he points out, to communicate with witnesses as to where they were in relation to other places, features and locations. Gross notes that the making of such models is time-consuming, especially if forests, buildings and annotations are included. His ultimate aim is to create a representation of the landscape both for his and other investigators understanding, as well as (presumably) a jury. Gross would have been amazed at the invention of stereo-pair aerial photography, digital terrain models and computer-assisted three-dimensional visualisation of the land, which are after all, very clever ways of doing what he was doing with clay models. Gross further demonstrates this in his Figure 35, where he depicts what is visible, or hidden, from a certain location. In this, he was demonstrating line of sight, or what is modelled digitally in a viewshed analysis using GIS. Again, this visionary concept of the use of physical geography in understanding covert activity has prompted us to re-draw Gross's diagram (Figure 2). What Gross does not amplify on is the applied use of his models: the search specialist or behavioural scientist investigating a missing persons case can instantly see the benefit. It is a pity that no photograph of Gross's clay topographic models now exist, as (like his 'Sketch of a of a Larger Portion of Country, our Figure 1) it would have been excellent to examine what he made and how he represented landscape features. Below, we will see how ahead of his time Gross was in that some recent studies have effectively been using Gross's ideas in geomorphically-based searches.

3. The Sociological Perspective: Rossmo's (2000) 'Geographic Profiling'

Rossmo states that 'geographic profiling is an investigative methodology that uses the locations of a connected series of crime to determine the most probable area of offender residence … developed from research conducted at Simon Fraser University's School of Criminology, the method is based on a model that describes the criminal hunt.' Rossmo goes further, in examining the spatial patterns produced by the hunting behaviour and target locations of serial violent criminals. Inherent in the above definitions are the association Geographic Profiling has with locating the offender's place of residence, an admirable aim in itself, but one that does not allow other aspects of geographic science, specifically geomorphology, to be included in either the definition, nor the application of geography to criminology, specifically understanding the interaction between the perpetrator and the landscape, as well as assisting in the search for items (buried or exposed) in a landscape. This is probably a function of statistics, as Rossmo states, only 2% of serial cases of the murderer encountering their victim occur in 'rural' or 'wilderness/uninhabited' locations (his Table 9.6, p 175). However, what he describes as 'body dump' (p. 175), or body deposition sites, show 5.8% in parks, 12.5% in rural or agricultural and 21.2% in wilderness of uninhabited areas of 'land use' (p. 175). These statistics are worth exploring, as they justify the limited use Rossmo sees for Geographic Profiling in the sense of predicting offender activity, but they do show how under-used geomorphology is in assisting the search for missing persons, especially murder victims (Table 1). Nonetheless, Rossmo's definition is somewhat contradictory, as one of the key examples he cites in the use of Geographic Profiling is that of the 'Catch Them' (CATCHEM) database (Burton, 1998), wherein distances from footpaths, concealment, burial, disposal in water are central tenets of Burton's work, which is equally applicable to the urban, peri-urban, rural or adjacent to aqueous environments. Furthermore, when Rossmo does consider elements of the physical environment (rivers, oceans, lakes, ravines [p. 214]), he sees them as constraining 'people': here we argue that while this is true of non-offenders, the perpetrator of a crime sees the above locations as places of opportunity, being covert and/or in a medium in which an object can be hidden. This is equally true of Keppel & Weis's (1994) analysis of murders in Washington State, which did not differentiate the geographical type of area, but considered instead locations where the victim was last seen, contacted (by offender or other), assaulted, murdered, and body recovered. These event locations may be coincident, but are useful, as they are not dependent on a type of location. In contrast to this study of murders, an FBI study of rapes (Warren et al., 1995), showed very low occurrence outside of the urban environment, and even then a low rate of rapes outdoors. Rossmo suggests arson has similar statistics. Interestingly, the one case Rossmo cites where Geographic Profiling assisted in the search for the body of a missing person, the case is rural in nature*, reflecting the main issue proposed in this article, that we agree with Rossmo, serious crimes are less common in rural locations, but that his definition of the geographic in Geographic Profiling precludes use of geomorphology in both understanding criminal behaviour (the interaction of the offender with the natural environment) and assisting in the search for missing persons.

*’In November 1993, a teenage boy was found shot dead in his parked car, and his girlfriend kidnapped, in New Brunswick. The murderer was identified through rifle ballistics, but disappeared prior to arrest. The Royal Canadian Mounted Police began to theorise that the missing female victim had been killed and the offender had committed suicide. Two searches failed to find evidence. A geographic profile was prepared and it identified two search areas using path analysis, journey to crime and time-distance-speed calculations. A search located items associated with the offender in a river under a railway bridge and the body of the female victim in a field. The former was in the highest prioritised area for search, the latter in the second.’

Rossmo’s New Brunswick case comes close to using mapping in crime analysis, in that he applies GIS to his analysis (his Chapter 10, pp185). Rossmo makes an excellent case for the use of computer-assisted spatial analysis of crime, with the proviso that such databases require quality information (rubbish in, rubbish out), which maybe lacking for criminal activity outside of urban areas. The power of analysing spatial mean and standard distance as a connected series can be increased by incorporating greater sophistication, such as street networks, freeway exits, and most critical for this review ‘other relevant landscape characteristics’ (p. 187). This, to our mind, includes the physical environment, wherein the ‘obstacles’ Rossmo considers as barriers can (regardless of use), be incorporated into a GIS in order to assist in the analysis of offender activity, and possibly provide a predictive model, although ‘future crime prediction can be a difficult task’ (p. 187).

Rossmo provides ample statistical justification for using geomorphology in the search for body deposition (‘dump’) sites, as opposed to criminal behaviour (see Table 1, based on Rossmo). The other elements where offender behaviour interact with the physical environment are included on p. 131, where Rossmo summarises the speed with which an offender can travel over different (all be they basic) types of terrain (a direct function of geomorphology) and how buried victims may be detected : in this latter section (p. 131), Rossmo refers largely to other works.

In conclusion, the geomorphological justification for including Rossmo’s book here, in comparison to the other publications reviewed, is slight. However, the background to the geographic location of criminal activity (especially the statistically-higher chance of body disposal being away from the urban environment), the need for some discussion of the use of the word ‘geographic’, and the indications that GIS will increasingly be used to analyse all aspects of the offender’s environment (not just locations, transport) make this a useful background to where geography is perceived and used in the law enforcement and search/rescue community.

4. The FBI (Federal Bureau of Investigation) Perspective: Boyd (1979) ‘Buried Body Cases’

Boyd (1979) considers the specific search for buried bodies (our approach is to widen the context to all covertly-buried materials). Many people concentrate on the surface expression of a burial – naturally because they are fixating on finding the victim (or other object). As Boyd shows, the succession of activity prior to, during, and after the burial are also critical, both as events that alter the landscape and give rise to the surface expression one is looking for, but also to reconstruct what has happened, when and how: the fundamental questions asked in geomorphology. Initially, there is the choice of a burial location: this is not considered by Boyd, but features heavily here, as landscape plays a huge part in the behaviour of offenders. At the would-be burial location, there is likely to be soil or sediment stratigraphy and sometimes vegetation. These are successively disturbed and have to be stored or removed (the latter is unlikely but does happen). The body (or other object[s]) is placed in the burial location, commonly elongate but sometimes dismembered, foetal, depending on constraints imposed by burial pit geometry (space available, tree roots etc.), or by *rigor mortis* in the victim. The grave is infilled with what is now foreign material: the excavated vegetation, soil, sediment and rock layers have now all been homogenized to make this effectively ‘new’ ground. Attempts to conceal the surface of the grave are rare in rural locations, common in urban; the former being often ‘left to nature’, while in the latter, building materials, flower-beds etc. are common, whereas bare earth is not, requiring concealment. Boyd summarises the offenders as having left: remnants of the excavated material around the edge of the grave, disrupted stratigraphy, damaged vegetation, foreign materials introduced (infill, human bodies, weapons etc.) and an unusual local geochemical environment. These are the features we (forensic geoscientists) currently use to locate graves (Harrison & Donnelly, 2008).

Boyd was considering the local affects of burial caused by one body. Two influences have been key in changing how Boyd's work would now be considered. First, the wider influence of the surrounding landscape is seen as important in determining where a burial is located (offender activity) and how it is located (see Harrison & Donnelly, 2008, reviewed below). This is largely the result of the improved resolution of satellites and aerial photography, the creation of digital terrain models and thus the possibility of understanding more about the landscape (rural or urban, or other) the burial has occurred in. Second, the publicised discovery of large burial sites (mass graves, illegal dumps, weapons and associated facilities) has increased since 1979 when Boyd wrote his article. Thus we see anthropologists currently concerned with remote sensing, geophysics and geomorphology when 20 years ago these were separate specialisms. Even if large-area data (maps, satellite photos) are not required in order to narrow down a search, they are often requested (a) in case the first search is unsuccessful – why have to re-trace your steps? And (b) to understand the landscape in context of other factors – offender behaviour, access, visibility, diggability and what may have happened in the area since burial (landslides, bog slides, flooding, dune migration). Hence many searches still begin with a desktop study of all the large-scale data available on topography (maps, digital terrain models), vegetation (maps, remotely-sensed data), soils and geology (maps, remotely-sensed data) and drainage (Harrison & Donnelly, 2008). Large-area maps (topographic, hydrology), digital terrain models and landscape interpretation are also needed when planning excavation activity for health and safety assessment of natural and induced hazards (flooding, landslip, subsidence).

5. The Criminalistics Perspectives

5.1. Killam on 'The Search for Human Remains'

Killam (2004) provides the most comprehensive work on the search for human remains, much of which can be translated to other objects buried or hidden in a landscape. Killam's book is based on a mix of criminalistics, archaeology, behavioural analysis and search and rescue. Throughout the text, Killam refers indirectly to various aspects of geomorphology, from murderers using 'paths of least resistance' (p. 17) to move victims (and thus routes that should be avoided by search personnel in case of compromise), to the need for those searching to take special care in searching downhill from any access, as the easiest path, but also one where remains will move or be moved by animals. Many of the aspects developed further by Harrison & Donnelly (2008) and McKinley et al. (2008) are mentioned by Killam, including (p. 18) graves likely to be in diggable ground, away from rocks and tree (roots), and in a secluded place, the latter being ideally suited to viewshed analysis. Killam also mentions pre-existing sites such as lakes, ponds, wells (not caves interestingly) and landfills. Killam notes how topography is not only important in the location of hidden objects (in his case, human remains), but should be used positively to assist the search itself (p. 27). The most obvious example he gives is deployment of a strip or line search that follows contours, providing maximum coverage of the ground, for minimal effort. The bulk of Killam's book comprises a description of search methods (dog deployment, soil compaction/chemistry, geophysics, remote sensing), with the chapter on aerial photography (p. 160 to 184) including the most implicit use of geomorphology, with discussions of vertical, oblique, stereo-pair photographs in visualising the landscape. Killam then discusses (p175) the interpretation of aerial photography, including how 'any anomalies noted on the ground's surface should be marked'. He discusses how such anomalies are discerned from natural features (p. 178) and lists the colour/texture of land and soil, field patterns, the shape of the land and shadows. An interesting addendum to Killam's chapter on aerial photography would be to have the same data interpreted by an archaeologist/search expert and by a geomorphologist and see what results compare and which differ.

5.2. Harrison and Donnelly (2008) on 'Locating Concealed Homicide Victims'

The principles of search that are explored and described by Harrison & Donnelly include many aspects of geomorphology, placed in generic language that allows translation of the principles to many types of environment. Central to their discussion of search methodology is the difference between 'Scenario-based' and 'Feature-based' searching. The scenario-driven method has close links to Rossmo's work (see above), wherein the known or predicted behaviour of both victim and perpetrator are considered, in this case in terms of where a body may be concealed. Key to this are likely distances travelled by both, and means of transport. Harrison & Donnelly play down the importance of the landscape in terms of the victim, who is largely out of control of where their body will end up. The main role location has for the victim is where they encountered the perpetrator – in this matter the landscape is important as it may also be the site of an assault, murder and body disposal. The landscape, and thus geomorphology, is far more critical in terms of the perpetrator's knowledge and behaviour, for the search specialist will be trying to replicate their thought processes in terms of where they know of covert locations, access, pre-existing hollows, tunnels, pits, caves and diggable ground. Less like Rossmo's more behavioural-based approach to the landscape, and more akin to traditional geomorphology, is Harrison & Donnelly's second search method, that based on 'Feature-based' or 'Feature-focussed' understanding. In this, physical aspects of the landscape are critical, as the offender rarely carries out all their activities in a random location, be this the observation ("hunting" of Rossmo) and stalking, attack, assault, murder and primary or subsequent stages of body disposal. Some elements of chance occur in the behaviour of the perpetrator, for instance in the location of an encounter with a potential victim. Other aspects have a greater element of control, for instance a planned burial. To some degree therefore, the offender operates in relation to a landscape, and especially its' distinctive features or a landmark (a rock, tree, lake, path, shape of hill, line of sight to a feature). Often the reason for one or all stages of the crime occurring near a landscape feature are obvious – to return and check for disturbance or maintain control of the corpse or evidence. Sometimes this is less obvious in that a landscape feature is present, but the reason why is not known or it was a subconscious act, or indeed a random chance. Other elements of Harrison & Donnelly's work have a strong basis in geomorphology – offender effort and topography, viewab~~b~~ility (viewshed analysis) and diggability (soil thickness and cohesion).

6. The Archaeological/Anthropological Perspective

6.1 Hunter, Roberts & Martin (1996) on the Archaeology of the Victim in the Landscape

Whilst many books encompass the application of archaeology/anthropology to forensics, most concentrate on excavation, identification of bones and pathology. Many do examine methods of detection (geophysics, scent dogs), but Hunter et al. (1996) consider more than other works the role of the landscape in search (here specifically for human bodies, unlike some of the works [above] that may be applied to all manner of buried objects. This inclusion of both the broad search (not just over a possible grave, but the whole area) is apparent in Hunter et al from their earliest pages, wherein photographs of the searches for victims of the Moor's Murderers (Ian Brady and Myra Hindley) are included, and a sub-section (p. 17) called 'The Landscape' leaves the reader in no doubt of how this work incorporates much more than the 'digging' archaeology familiar to all. This section raises some of the fundamental questions of where is 'diggable', and why a desktop study of topographic maps so useful in planning and conducting a search. These aspects are expanded upon in the key chapter (Chapter 5, pp86-100), where the writers (for this chapter, Hunter and Martin were the authors) consider some background (including parapsychology) and then outline a useful 'macro to micro' approach to the terminology of search, from the search area (all of the terrain), burial site (the grave and associated disturbance), the grave (only), search indicators (ground abnormalities) and vegetation. The concept of 'near-field' (around the grave) and 'far-field', the undisturbed surroundings, is introduced from work by France et al., 1992), from work in North America, and again recognises the importance of the burial site in the context of the landscape, as opposed to it in isolation. Hunter et al, use Killam (see above) as one of their sources when describing soil disturbance and the subsequent changes in vegetation, and go further in discussing how in temperate climates, a body buried in impermeable ground may promote plant growth above, yet when the body is covered with stones or stony soil, the opposite may occur. The problem of observing soil disturbances after some time has passed is considered, and Hunter et al consider some solutions such as observing the ground in low light conditions and interpreting aerial photographs from a combined archaeological/geographic perspective, to highlight non-natural features. Archaeologists are well-versed in using aerial imagery, and Hunter et al's case study (p. 91) is an excellent example of how fortuitous use of historic imagery allowed a search for a missing woman to be narrowed down, saving human and financial resources in what would have been a fruitless search. While strictly an exercise conducted over a non-natural area (and thus not strictly the use of geomorphology), the study uses the same principles of changing land-use, vegetation, perpetrator access to define a search area. A critical point is made on p. 93 concerning how to appraise a landscape – 'an assessment of what is or what is not likely to have been possible, and the subsequent delimitation of target areas', reflecting the macro to micro ethos these authors recommend. They consider the desktop study of topographic and geological maps as informing deployment of geophysical and other search assets, which is exactly what later authors have done in their work, making Hunter et al.'s work the standard from which others have followed and developed. As mentioned above, Hunter et al quote Killam (see above) and France et al in their work, such that a brief summary of the latter is useful in this review.

6.2. France et al. (1992) on the Multidisciplinary Approach to the Detection of Clandestine Graves' France et al. (1992)

France et al (1992) state that 'only a few studies listed in the literature concentrate on multidisciplinary methods directed toward the location of buried human remains', which is reflected in the fact that Boyd is their key paper, also reviewed here. What is novel about this work~~,~~ is the temporal aspect to their study, in that they buried pig carcasses in different geological, topographical, soil type locations in Colorado, and then deployed a variety of search methods over a period of years to see how well the burials could be detected. A variety of landforms and soil types and thickness was key in selecting the burial sites. The range of geomorphological locations was not further considered by the authors, as they were aiming to test the usefulness of search assets over time. An interesting aside is that the authors were partly mimicking perpetrators in their experiment, as they needed diggable ground, but probably not a covert location. Soil permeability, slope aspect and rainfall all played significant parts in influencing the effectiveness of the search methods France et al. (1992) deployed, aspects that have also been researched from the perspective of the decay of human remains researched at the University of Tennessee research facility known as ‘The Body Farm’ (Rodriguez & Bass, 1985).

7. The Geoforensic Perspective

7.1. Pringle et al., (2012) on the Forensic Search for Buried Objects

This work provides a context in which geomorphology and landform mapping is used in the branch of geoforensics known as search. Pringle et al. (2012) review the methods used from the large scale of a landscape (maybe tens to hundreds of km) down to the site of an individual or mass burial (tens of metres down to decametres). In the middle of this range of scales, they consider geomorphology, having described remote sensing in a similar way, from satellite and aerial platform imagery, through specialised remote sensing techniques (infra-red, ultra-violet, multi- and hyper-spectral), before they look at ground searches for specific targets. In their review, geomorphology is reliant on remote sensing, historical and land-use maps, but also key to determining the next stage of the search, and the methods that will be suitable for the work, from probing the ground, cadaver or missing person’s dogs, or the core of their paper, geophysics.

7.2. Ruffell and McKinley (2008) on Landform Mapping and Geomorphology

In their chapter on physical geography, the above include all elements of the Earth system (water, air, soil/rocks and organisms) in the context of forensic investigations. Their sub-section on geomorphology includes explanatory material for the non-specialist (the nature of landforms, their evolution and classification), such that some examples are shown. They then go on to explain in further detail what elevation modelling is and give some indications (e.g. using line of sight to predict where a covert location may be) as to how this maybe used in search. The sources of data (satellite, aerial) and their manipulation (stereo-pairs for topographic modelling) are considered in terms of geomorphology. They use a case study that is expanded on in this work (see McKinley et al, 2008, below). Ruffell & McKinley use some elementary examples in order to demonstrate to the reader how geomorphology has been used in many famous cases, possibly without it being obvious to the general public that the knowledge was not everyday information but had a scientific basis. They include the following examples. In the case of the hunt for Osama bin Laden, the geological succession exposed in a cave from which bin Laden made his famous 'post 9-11' broadcast, was critical in identifying his rough whereabouts in northern Afghanistan. Karst features also figure prominently in the description of how solution hollows (dolines) were misinterpreted by Allied Reconnaisance as bomb craters prior to the D-day Landings. D-day was also used to show how important understanding coastal geomorphology was in negotiating rocky reefs, steep cliffs and soft sand from beach assaults. The invasion force undertook extensive studies from submarines, aerial photography and covert landings, prior to the invasion in order to plan the best locations for landing craft, parachute, battleship gunnery and cliff-scaling assault to cope with the variable coastal geomorphology of the Normandy coastline. Ruffell & McKinley complete their physical geography chapter with an unpublished example of how a search for buried bodies in the Middle East did not take account of the timing of the disappearance of a missing person and a nearby landslide, which covered the victim. The presence of an isolated tree, where weapons were found focused the search on object-based grounds (see Harrison & Donnelly, above) and not feature-based (the landslide).

7.3. McKinley et al. (2008) on Geographic Information Science, Remote Sensing and Landform Mapping

In the search for a missing person, McKinley et al. (2008) assisted the police because a known serial killer was the last person to be seen with the victim, and the alleged perpetrator was seen near the search location. This search area was delimited naturally by a substantial river, a busy road and impassable peat bog (Figure 3). The authors decided to use a landform mapping approach in order to understand the landscape. They collected ground-based ~~LiDar~~ LiDAR and differential GPS for topographic mapping, tied into military reconnaissance aerial photography. These allowed division of the area into what the authors termed ‘domains’, or topographic divisions with distinct morphology, vegetation, soils (especially thickness and thus diggability), hydrology and viewability/access. The approach was thus a blend of some of the works cited above, especially Harrison & Donnelly (2008), Killam (2004) and Rossmo (2000). McKinley et al prioritised these domains using a mix of criteria, from 10 being least likely and 1 being the most likely, being most covert (viewshed analysis from LiDAR/GPS/aerial photography), diggable (soil mapping), behavioural (distance to vehicle access). This was used to focus deployment of a cadaver dog and carry out water sampling in a focused ‘search area’, both for the detection of human remains. The use of landform mapping, allied to other assets (vegetation, soils, behaviour) saved police time in searching the whole area. In order to demonstrate this process from a landscape interpretation (combined with behavioural analysis), the area shown in McKinley et al. (2008) is here reproduced, but with a conventional set of observations (Figure 3).

8. Associated Uses of Geomorphology and Landform Mapping in Investigations

8.1. The Military – Humanitarian Perspective

Military applications include both the planning of (and understanding past use of) transport routes, strategic high ground in battles and the location of covert activity in low ground (Gregory, 1918; Collins, 1998; Caldwell et al. 2004). Forensic geomorphology in humanitarian investigations overlap to some extent with other criminal investigations, for instance viewshed analysis and lines of sight applied to the locations of covert activity (mass executions, mass graves). Other areas include assisting post-disaster searches (landslides, tsunami), in which pre- and post-event topography and land use are critical, as reviewed below. A separate review article to this one could be written on the role of geomorphology in military campaigns, given that the preeminent workers on the subject (see the selected publications of Doyle, Bennett and Rose, below) often use the term ‘military geology’, when physical geography, land-use and vegetation are also considered. Military geomorphology is justified in its brief (but relevant) inclusion here, as an analysis of what happened, where and how, as in criminalistics, engineering or environmental enquiries. So inter-related is geology with the landforms it influences, it is hard to draw individual geomorphological examples from the works of Doyle & Bennett (1997, 1999, 2002) and Rose & Mather (2010, and references to military hydrogeology therein). However, some examples do stand out: they are numerous and thus only summarised here, the reader being urged to consult the original publications for greater detail. Topography (and the associated effort in getting up it, as with body disposal) has the greatest role to play in non-urban warfare through the ages. Since before documents have been kept~~,~~ men have fought each other individually and in groups, ~~and the~~with higher ground, while exposed, ~~has~~ nearly always providinged the advantage. Some classic examples are listed below. High ground was of advantage in Thermopylae, Hastings (to the English forces, prolonging their defeat by the French) and Gettysburg, to name only a few. Topography influenced (to the point of controlling) troop movements and action in the Somme (WW1), Verdun (WW1), Gallipolli (WW1), Monte Casino and Salerno (Italy, WW2), the D-day Landings (WW2) and Hill-137 (Vietnam). However, notable exceptions occur. In the Battle of Jieting (China, 228BC), the defensive army of Wei was surrounded on the high ground of an isolated hill, forcing their defeat and surrender. It is unfortunately inevitable that the horrors of international and intra-national (civil) war go hand-in-hand with humanitarian crimes such as mass burial (Nazi death camps, Cambodia, Rwanda, Bosnia), where remote sensed detection of mass graves, the geomorphological control on their location (water flow, soil depth) and topographic influence on visibility make landform interpretation a key element to image interpretation (Kalacska & Bell, 2006; Skinner et al., 2003; Davenport, 2001). The methods used have also been deployed in post-disaster management, as remotely-sensed images are often all that can be safely obtained following an incident. Satellite imagery was key to deployment of resources following the Gujarat, Boxing Day Tsunami and Haiti disasters. An excellent example of this type of combined remote-sensing and geomorphic mapping is given in Wescoat & Kanda (2012), who used a classic three-stage approach (desktop study using remote sensing; on-site recording of tsunami effects using transect mapping; off-site analysis of the data) following a 11th March, 2011 earthquake and tsunami in Japan.

Commented [JM2]: isolated hill or knoll being the key here

8.2. Environmental and Engineering Forensics

Environmental applications may include the analysis of slopes, associated water flow, and thus be important in predicting and analysing pollution spills. Forensic geomorphology also overlaps with forensic engineering, as the latter is often concerned with enquiries into why structures (buildings, bridges) failed. Sometimes this is to do with poor construction, or poor foundations/slope stability, or sometimes a combination of both. The main application of geomorphology to environmental issues lies in tracking pollutants (as well as their causes and effects) in soil and water courses. The number of publications where this is central to the work is enormous, as a web search of the words the key words (above) reveals. Publications where the forensic (pertaining to the law) aspect is a focus are fewer, as the bulk of the literature concerns processes and methods, as opposed to criminal actions which feature in the forensic literature. Some of the issues are the same as in the types of serious crime considered elsewhere in this article, ranging from the macro-scale of landform mapping (Brilis et al., 2000) to the micro-scale of soil, sediment and water analysis (Fitzpatrick, 2012). For instance Small et al. (2004) and Rowan et al. (2012) used the same term (‘sediment fingerprints’) Bull & Morgan (2006) use in their consideration of using quartz sand grain textures as a discriminant in soil and sediment forensics. Rowan et al. (2012) use particle size distributions and geochemistry in their typing of sediments in Lake Bala (Wales, UK), which are methods also commonly used in serious crime forensics. Papastergios et al (2010) used a similar approach (using sediment geochemistry) in tracking marine pollution from the fertilizer industry (northern Greece). Many of the soil geochemistry-based publications concern tracking radioactivity in soil movement, erosion and sediment depositional systems (Ritchie & McHenry, 1990; Tyler & Copplestone, 2007). Fitzpatrick (2012) and Fitzpatrick et al. (2009) see no difference between serious criminal cases (in the sense of this article) and environmental forensics, both being subject to examination in courts of law.

9. Conclusions

The early work of Gross and the sociological context of Rossmo, both show how criminals operate in a landscape, which in rural (and some other) locations is better understood by mapping and developing theories of landform evolution. The criminal, victim, law enforcer and investigator all interact with this landscape and thus forensic work will be advanced by the input of a geomorphologist. The cognate disciplines of archaeology, geology, civil engineering and remote sensing have all benefitted from numerous publications demonstrating their use to criminal, environmental and humanitarian forensic investigations, when in rural settings geomorphology lies behind all of these applications, yet has not had such exposure. This is strange when the two strands of geoforensics; namely search (remote sensing, mapping, geophysics, archaeology) and sampling/analysis (soil and sediment mineralogy and geochemistry), both rely on understanding the landscape and its evolution. The authors strongly suspect that many areas of geoforensics use some knowledge of physical geography without necessarily acknowledging this, nor involving the specialist in say, landform mapping from remote sensing. This also seems bizarre, given as Schumm (2005) states “I have found highly qualified geomorphologists reluctant to be involved in cases in which they clearly could contribute to an appropriate outcome”. Hopefully, by showing that geomorphology has an important historical legacy, and is the backbone of all the other geoforensic techniques, this deficiency that criminal investigations suffer may be redressed. Likewise, difficult though the work can be, other Earth scientists need geomorphologists in investigations, whether they be serious crime or environmental. The wider applications of forensic-type geomorphological work to engineering, military and humanitarian investigations shows that it is not all about television programmes such as ‘CSI’ (Crime Scene Investigators) and murders, in today’s litigious society there are a multiplicity of roles for the geomorphologist.

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Figures.

Figure 1. Gross's (1894) Figure 34 (p.248) 'Sketch of a larger portion of country'. Gross's original was hand-drawn, this version is digital but otherwise faithful to his original. Gross provided no key to the diagram, so we presume (from left to right) the features shown are a quarry (lower left), field boundaries, different crop types and small forest (centre), a river, houses and church/graveyard (far right). The lettering represents his x,y grid notation.

Figure 2. Gross's (1894) Figure 32, showing his view of a line of sight, some 100 years before its common derivation from digital data. In both Gross's view, as well as modern criminalistics, such a model can be used to predict both where an offender is hidden from, as well as where a search team may see a victim.

Figure 3. The location of a police search for a missing person, with landscape and behavioural interpretation. The same area was used to demonstrate the use of digital data in McKinley et al. (2008). Reproduced from Land and Property Services data with the permission of the Controller of Her Majesty's Stationery Office, Crown copyright and database rights MOU203.

Table 1. Geographical analysis of areas where murderers encountered their victims and disposed of their remains. Simplifed from data in Rossmo (2000).

Area Land Use	Encounter	Body Dump	All Sites
Residential	45.8	45.2	45
Commercial	43.2	3.8	24.4
Industrial	0	5.8	3.4
Institutional	3.2	1	1.9
Park	1.3	5.8	2.5
Rural or Agricultural	0.6	12.5	5.3
Wilderness or Uninhabited	1.3	21.2	9.1

Site description	Encounter	Body Dump	All Sites
Residence	29	17.3	27.2
Hotel or Motel	0.6	0	1.3
Public Building	1.3	0	0.6
School or Educational	0.6	0	0.3
Business or Shopping site	11	1	7.8
Entertainment site	5.8	0	2.8
Red-light zone	23.2	0	11.3
Vehicle	6.5	5.8	11.6
Public transport	10.3	1	5.3
Private yard	1.3	5.8	2.5
Parking lot	3.9	2.9	3.4
Street or sidewalk	51	16.3	34.7
Alley, lane, path,	0.6	11.5	5.3

trail			
Highway, ditch	5.8	3.8	5.6
Park	1.9	6.7	3.1
Field/open	0	11.5	4.1
River, lake, marsh	0	21.2	8.4
Forest/woods	0.6	21.2	8.4
Hills/mountains	0	4.8	1.6
Desert/wasteland	0	3.8	1.3